Higgs searches

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on behalf of the ATLAS, Babar, CDF, CMS and D0 collaborations

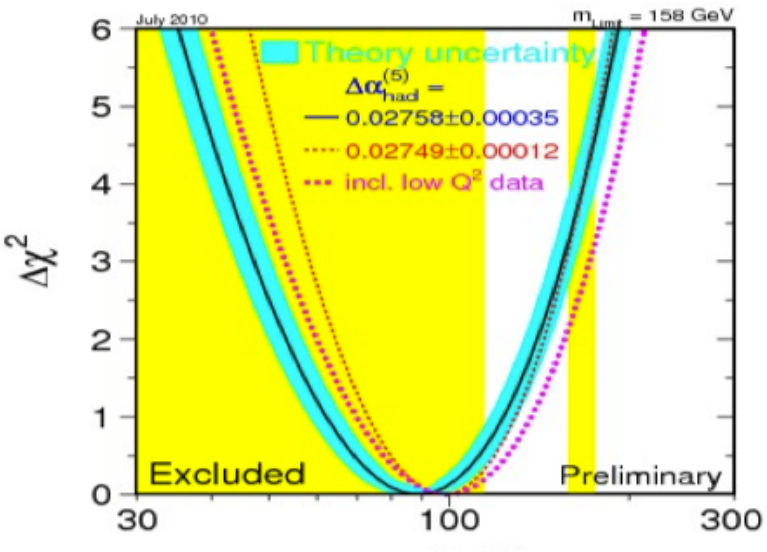

Note

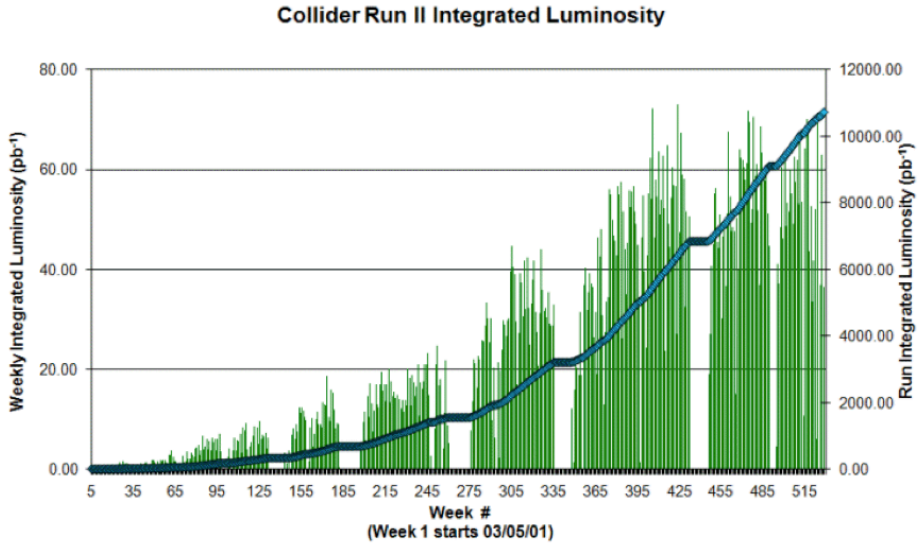
- Many **analyses**
  - probing all **production** mechanisms and **decay** modes
  - taking advantage of **multivariate** techniques for improved discrimination
  - using growing datasets (up to **8.2 fb^{-1}**)

- **We didn't find it yet**
  - I'll give an overview of the latest results

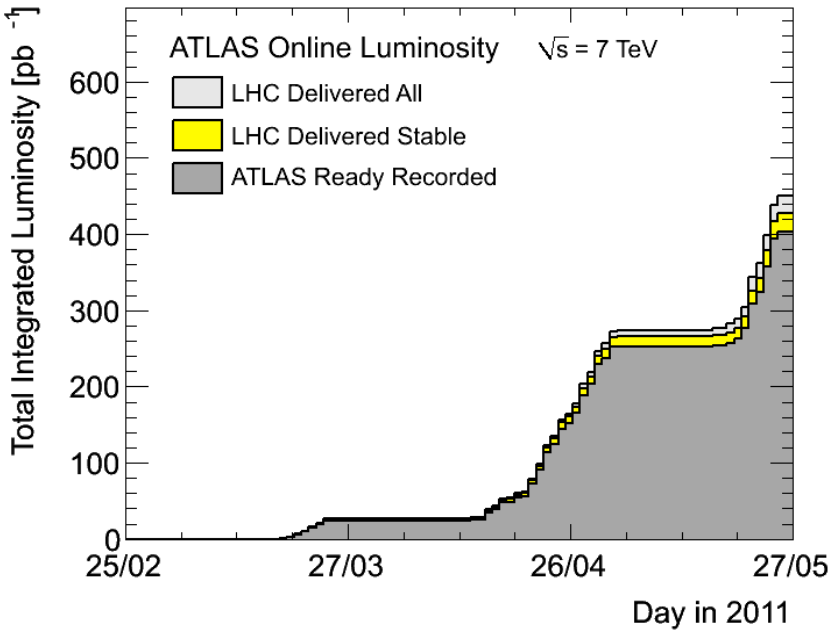
- After a very short introduction, I'll show the latest SM Higgs searches results and then some new BSM results

LHC, Tevatron & the Higgs boson





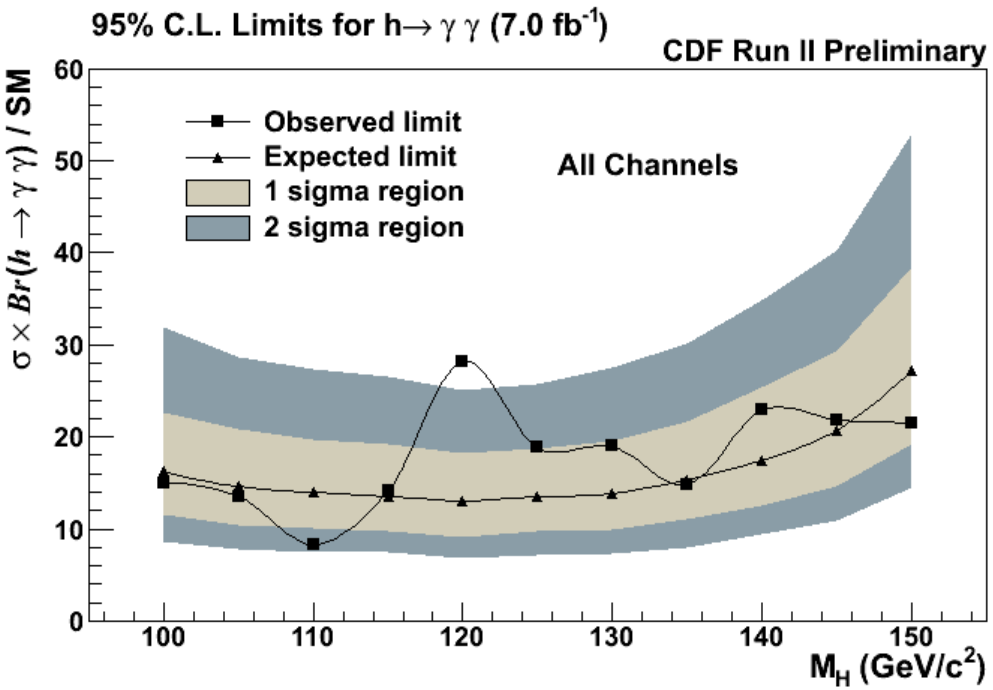
- **LHC** luminosities ramping up fast
  - about 40 pb^{-1} in 2010
  - about **400 pb^{-1}** in 2011
- **Tevatron** has already delivered above **11 fb^{-1}**
- Electroweak fit prefers **m_H<185GeV**

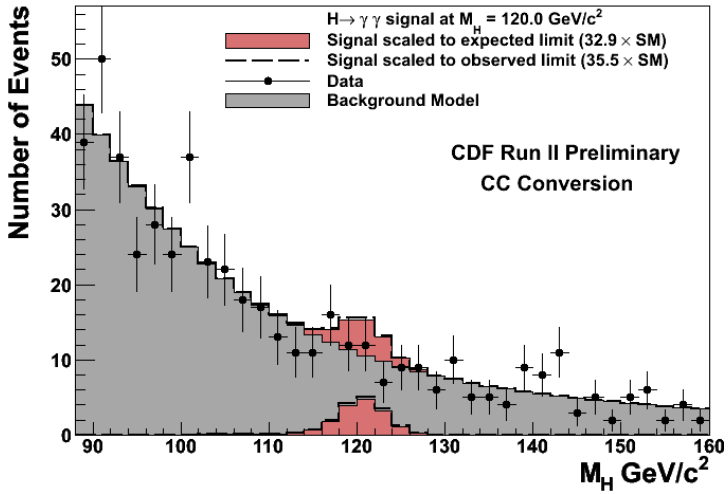


luminosity 7.0 fb^{-1}
exp limit@115 GeV/SM 14
obs limit@115GeV/SM 14

Higgs → γγ

- Smaller branching fraction that bb decay channels, but better ID efficiency and energy resolution
- New result benefits from
  - extended acceptance in pseudorapidity: up to 2.8
  - neural network,NN, based identification
  - inclusion of converted photons





- Null hypothesis is assumed: fit serves as background model (smooth curve)
- Limits: binned likelihood
- No significant excess when trials factor accounted

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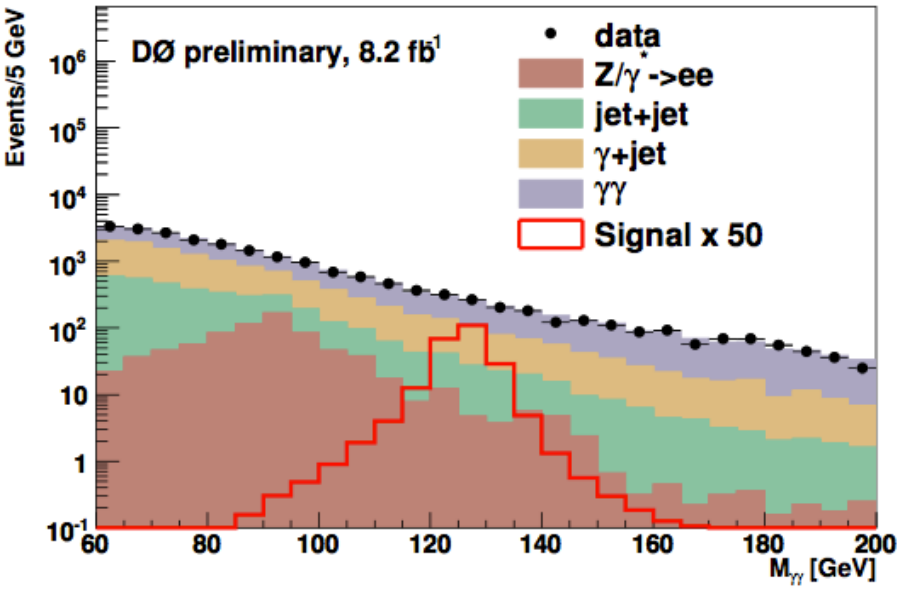
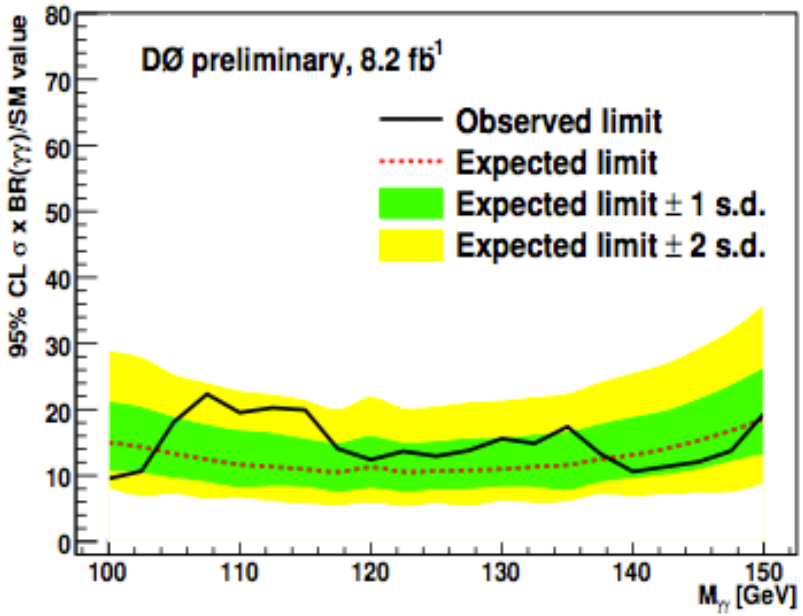
luminosity 8.2 fb^{-1}
exp limit@115 GeV/SM 12
obs limit@115GeV/SM 22

Higgs → γγ

- Event selection: two photons E_T>25GeV
- NN used to discriminate between jets and photons
- Main backgrounds arise from:
  - Drell-Yan and diphoton: estimated from MC
  - jet+γ and dijets from data with a matrix method
- Biggest systematic uncertainties from sample normalization and theoretical uncertainties. Integrated luminosity and data/MC factors also accounted for
- A BDT is used as final discriminant, shapes fitted for limit calculation





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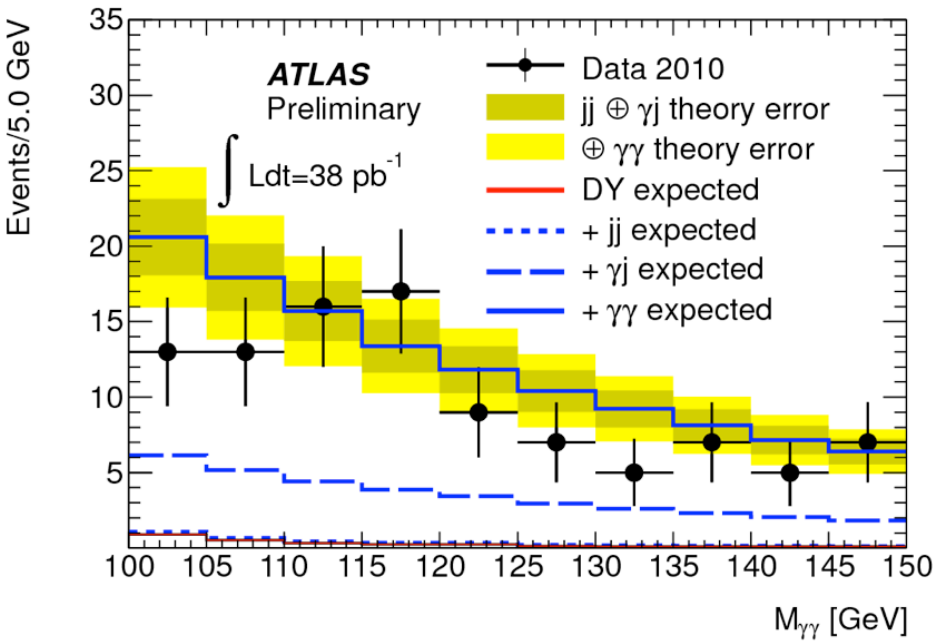
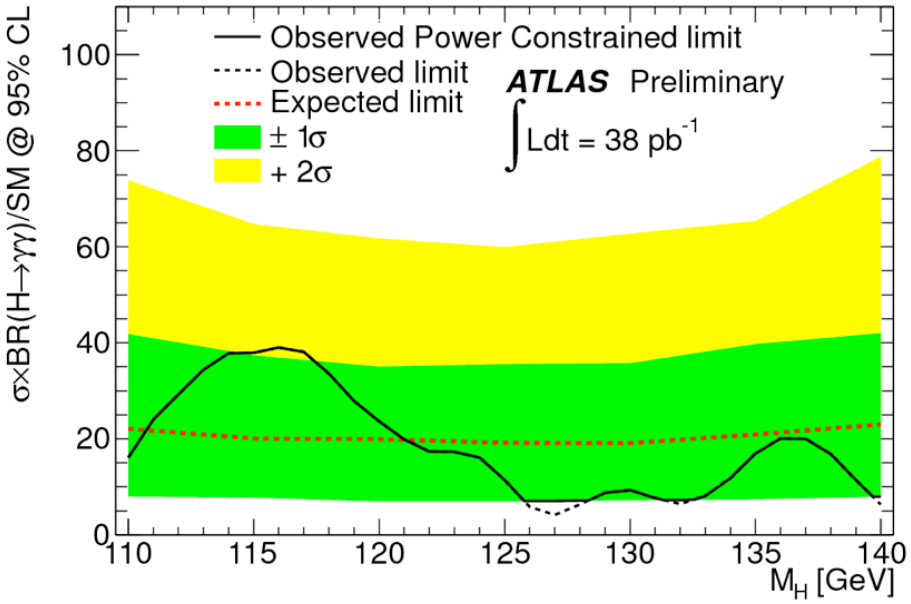
luminosity 38 pb^{-1}
exp limit@115 GeV/SM 20
obs limit@115 GeV/SM 38

Higgs → γγ

- Event selection:
  - at least 2 central isolated photons with E_T > 25GeV, one with E_T > 40GeV
  - at least one good reconstructed vertex
- Main backgrounds: jet contamination and non-resonant γγ
  - estimated in isolation/ID sidebands
- Systematics include luminosity, theory, efficiency (inc. trigger) and resolution
- Power Constrained Limits, with profiled likelihood ratio





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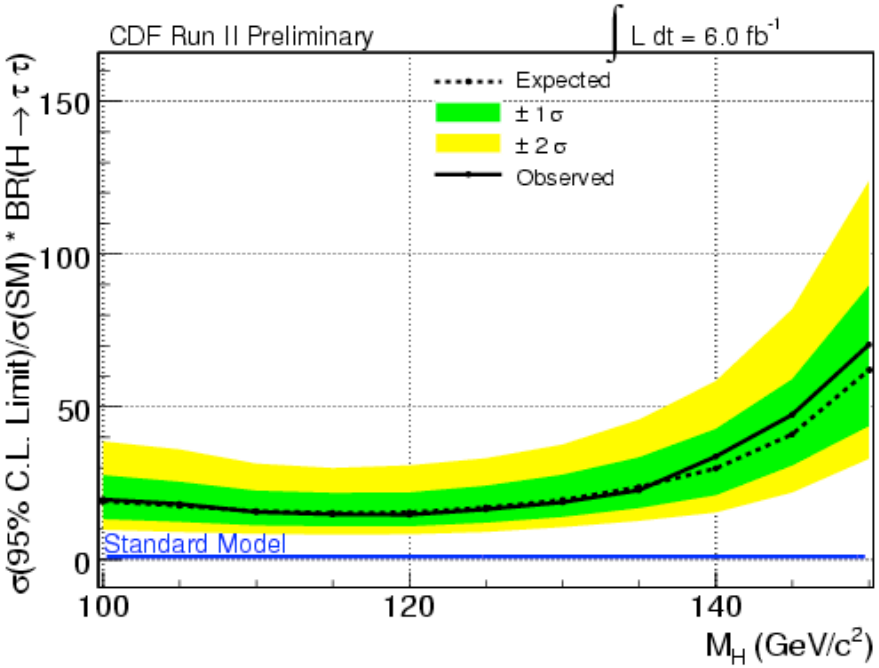
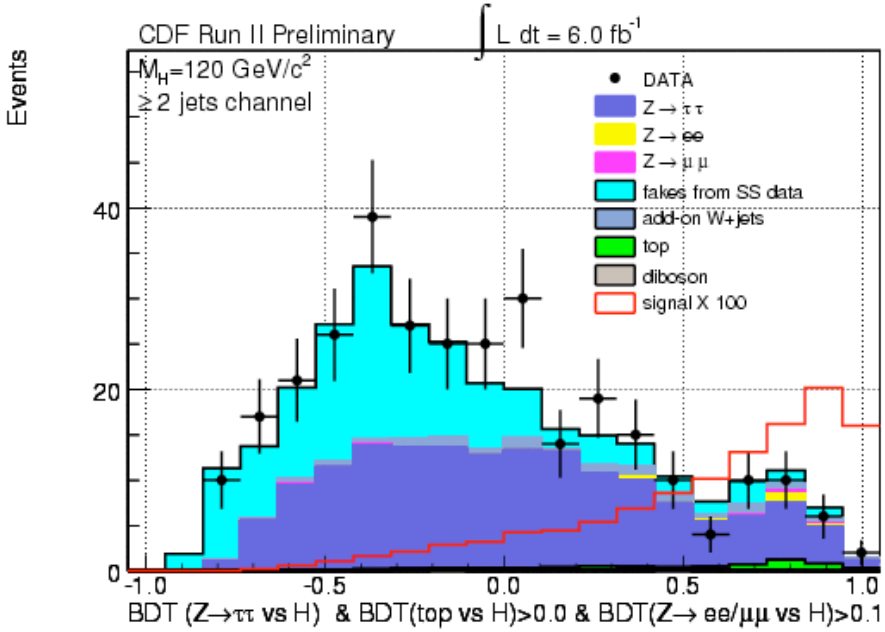
luminosity 6.0 fb^{-1}
exp limit@115 GeV/SM 15
obs limit@115GeV/SM 15

Higgs → ττ + 2 jets



- Associated production, vector boson fusion and gluon fusion
- Event selection
  - one hadronically decaying tau
  - one electron or muon
  - at least one jet

- Irreducible backgrounds estimated from MC: Z+jets, top pairs, diboson,..
- Fakes calculated in data
- 1-jet and ≥1jet optimized separately
- Bayesian 95% CL exclusion limits are set with BDT score templates simultaneously fit for both channels



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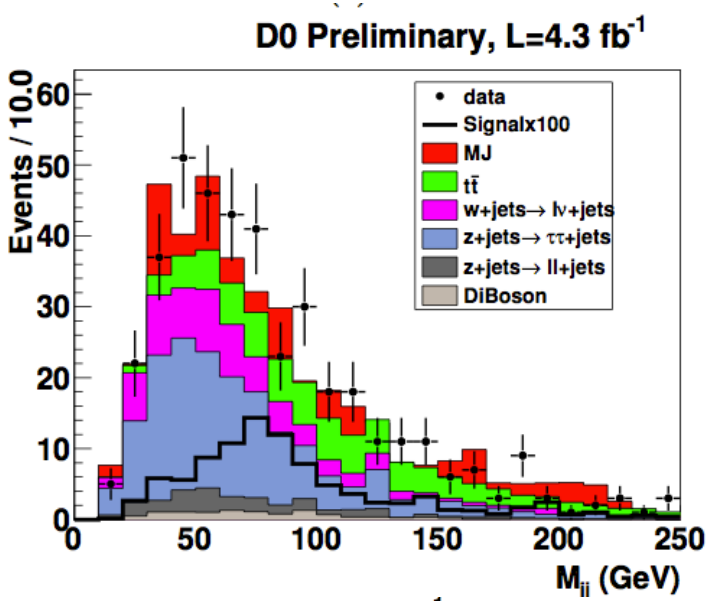
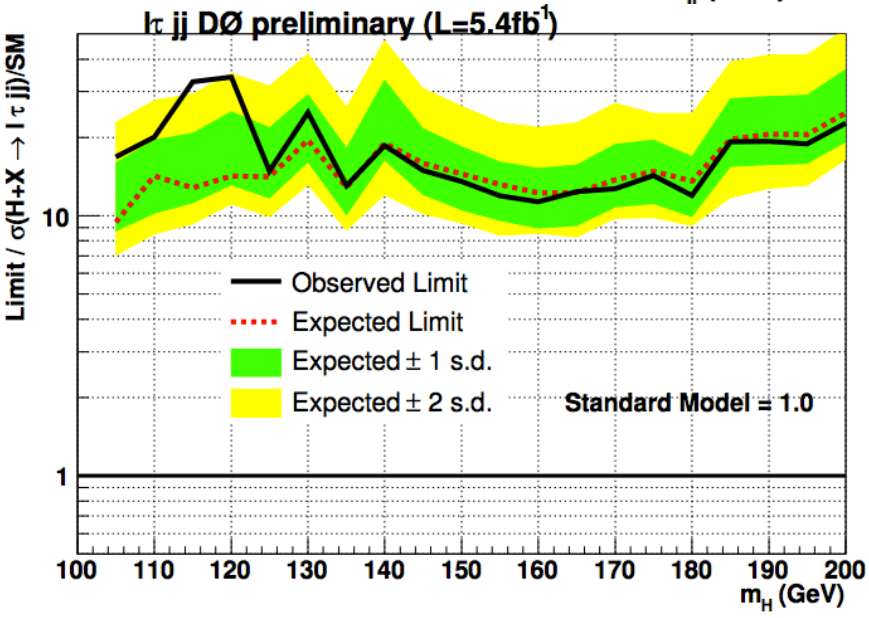
luminosity 5.4 fb^{-1}
exp limit@115 GeV/SM 10
obs limit@115GeV/SM 12

Higgs → ττ + 2 jets





- Considers H → ττ and H → WW, from direct, associated and VBF production
- Final state: one e or μ, one hadronic τ and 2 jets.
  - Hadronic taus identified with NN for different decay modes
  - A cut on missing E_T significance reduce backgrounds
- Main backgrounds are top-pairs, Z and W +jets, multijets and diboson
  - multijet is estimated from data by reversing lepton cuts and computing same-sign to opposite-sign ratio
- A BDT is trained for each combination of production mechanism, decay mode and mass rang. The output shape of a final BDT is used to extract limits

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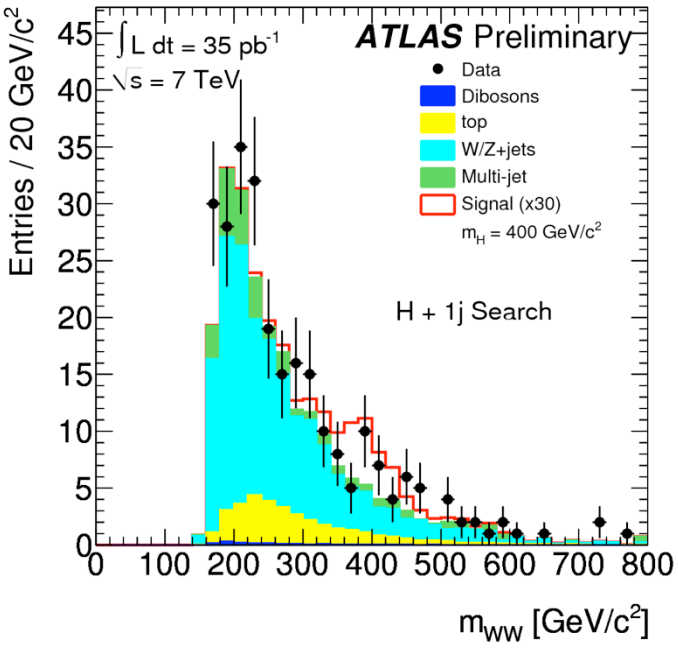
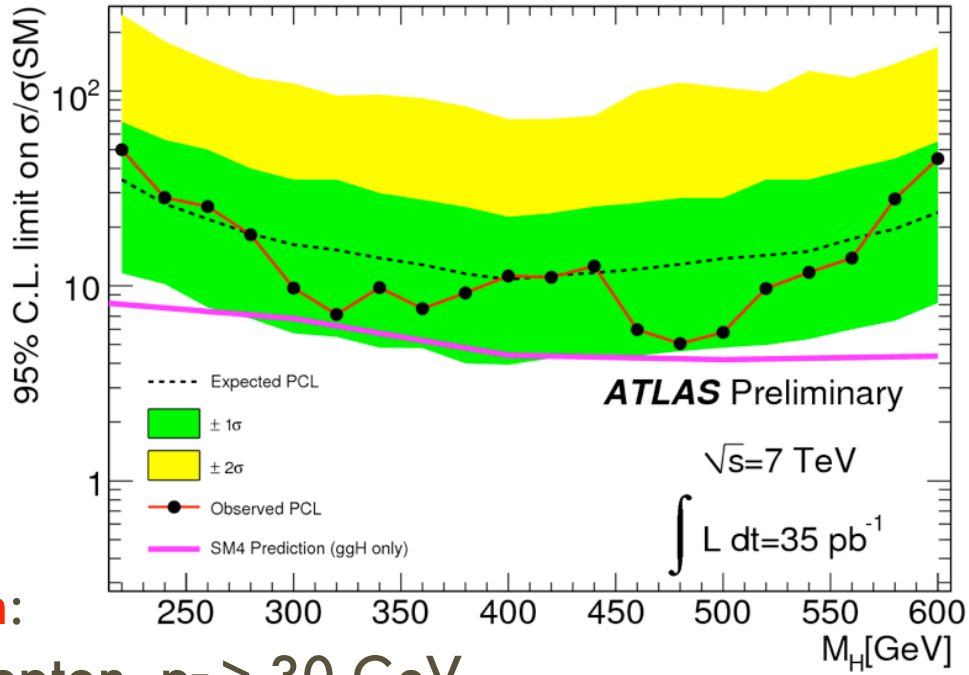
luminosity 35 pb^{-1}
exp limit@400 GeV/SM 11
obs limit@400 GeV/SM 11

Higgs → WW → ℓυ + 2 jets

- Production mechanism: gluon fusion and vector boson fusion
- High mass oriented search
  - 200 < M_H < 600 GeV
- Limits also on 4th generation
- Main backgrounds: W+jets and top-quark pairs, modeled with Alpgen and MC@NLO





- Event selection:
  - only one lepton, p_T > 30 GeV
  - missing E_T > 30 GeV
  - two or three jets, E_T > 30 GeV, with two of them with invariant mass consistent with the W
- Exponential fit to the background to set limits with a profiled likelihood (systematics as nuisance parameters)

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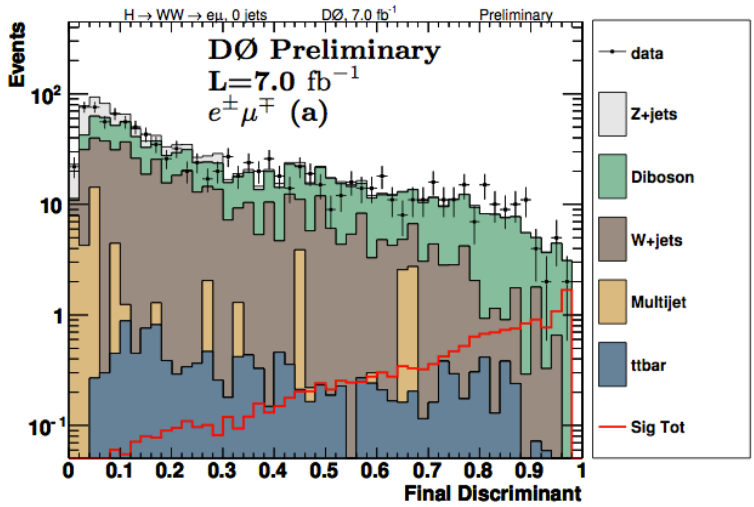
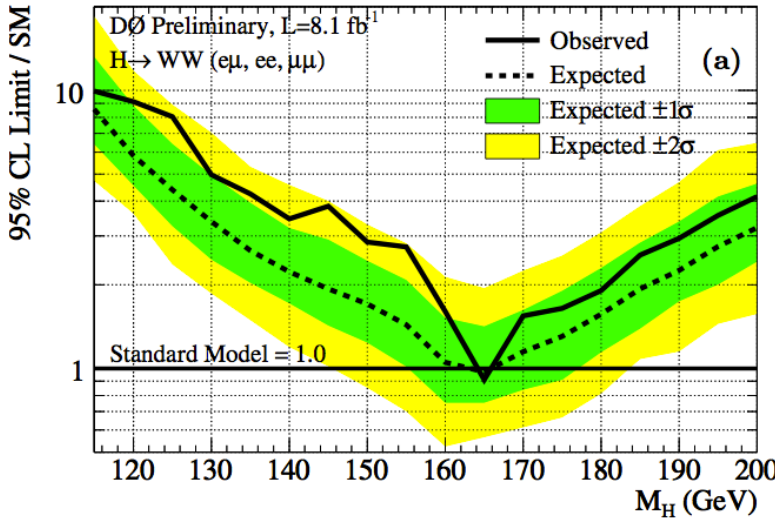
luminosity 8.1 fb^{-1}
excludes m_H = 165 GeV

Higgs → WW → 2ℓ+2υ

- Gluon fusion is the main production mechanism, but VBF and associate production are also considered
- Search for final states with oppositely charged leptons: ee, μμ and eμ, and missing E_T
- Backgrounds: diboson, Z, W+jets, top pairs and QCD
  - multijets: from sidebans (anti-ID) and checked in same-sign
  - rest from MC, W via fakes normalized in control sample
- 0, 1 and 2 jet considered separately, training two different BDT for signal to BG discrimination
- BG normalizations are the biggest systematic uncertainty
- Limits with CLs on final BDT discriminant shapes





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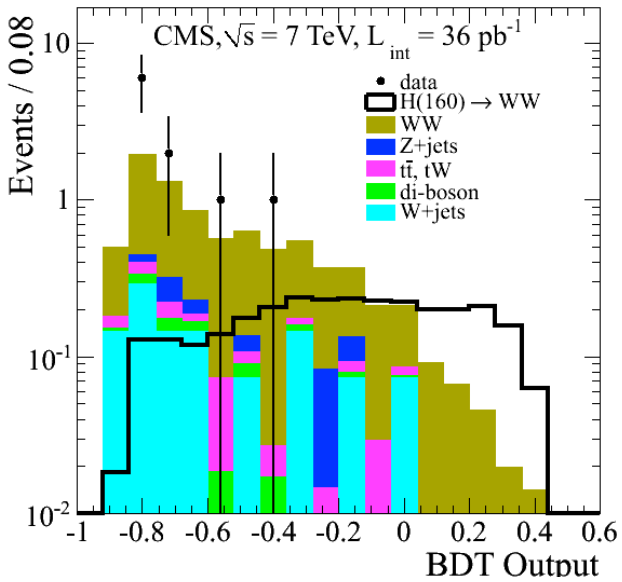
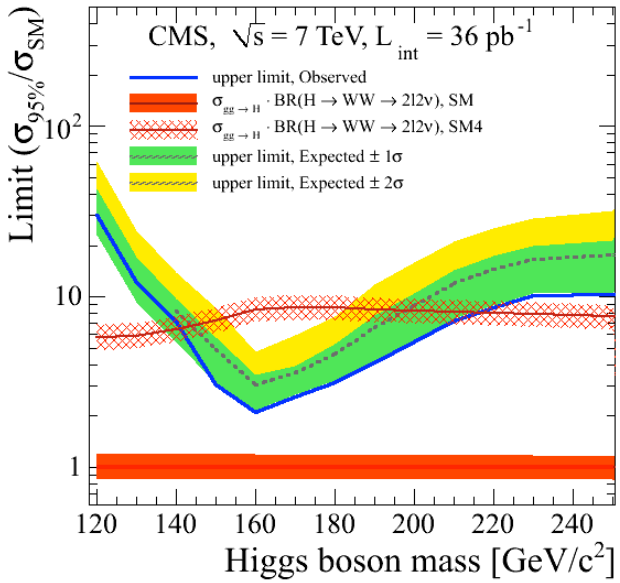
luminosity 36 pb^{-1}
exp limit@160 GeV/SM 3.4
obs limit@160 GeV/SM 2.4

Higgs → WW → 2ℓ+2υ





- Event selection based on
  - two opposite charged isolated high p_T electrons or muons from the Ws: E_T>20 GeV and $|\eta|$<2.4
  - large missing E_T > 20 GeV
- Analysis measures WW cross section, searches for SM and SM4 Higgs
- Main backgrounds: WW, W+jets, Z, top pairs
  - event level cuts applied to reduce their contributions
  - W+jets, Z and top are estimated with data-driven techniques
- Two methods: cut-based selection and BDT
  - cut based is based on $m_{\ell\ell}$ and $\Delta\varphi_{\ell\ell}$
  - BDT uses other additional angles
- Systematic uncertainties on background are dominated by stats in control regions, 40%
- 95% CL exclusion limits were extracted using a Bayesian and CLs, yielding very similar results

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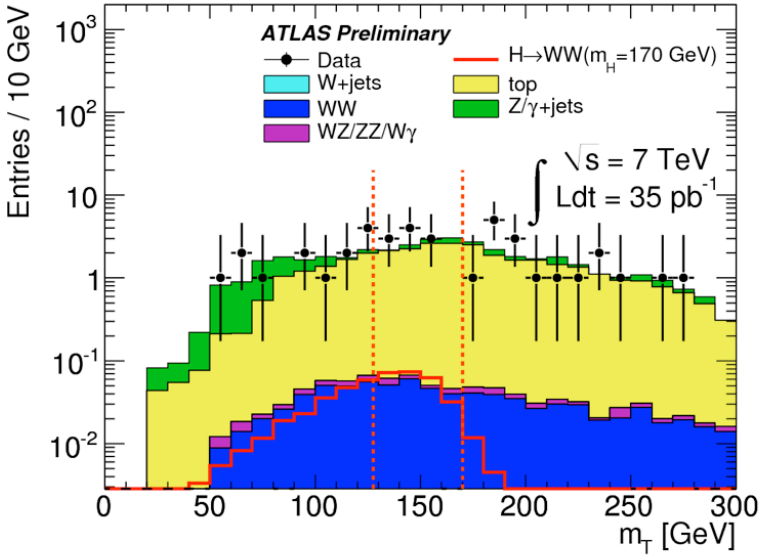
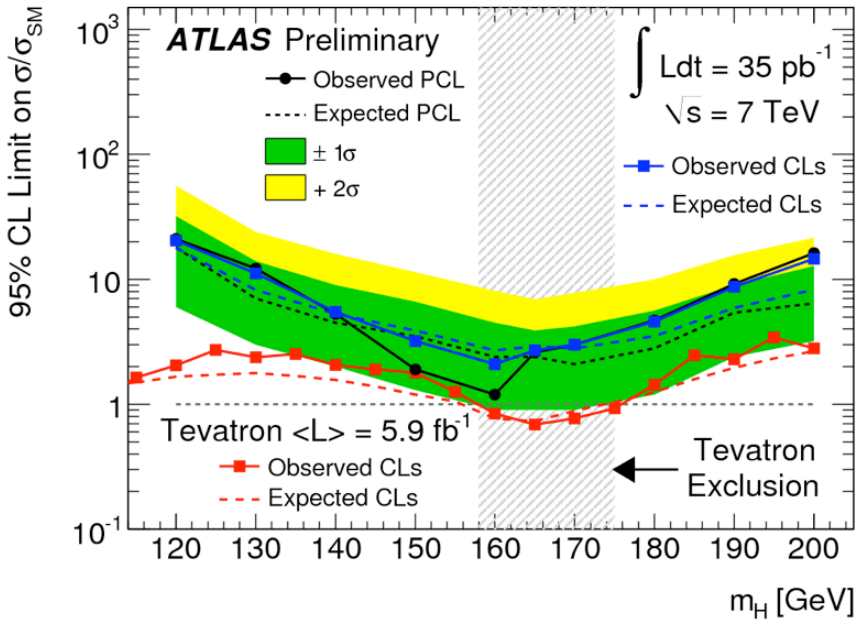
luminosity 35 pb^{-1}
exp limit@160 GeV/SM 2.4
obs limit@160 GeV/SM 1.2

Higgs → WW → 2ℓ+2υ



- Event selection:
  - two opposite charge leptons with at least 20 and 15 GeV
  - missing E_T>30GeV
  - small opening angle
  - extra requirements in some channels
- Likelihood fit of all channels to extract limits

- Process generated thru gluon fusion and vector boson fusion
- Major backgrounds:
  - t-quark, W+jets, Z+jets, WW
  - estimated from data with correction factors from MC
- Sample split in several channels:
  - ee, μμ and eμ
  - extra jets in the event: 0, 1 and 2



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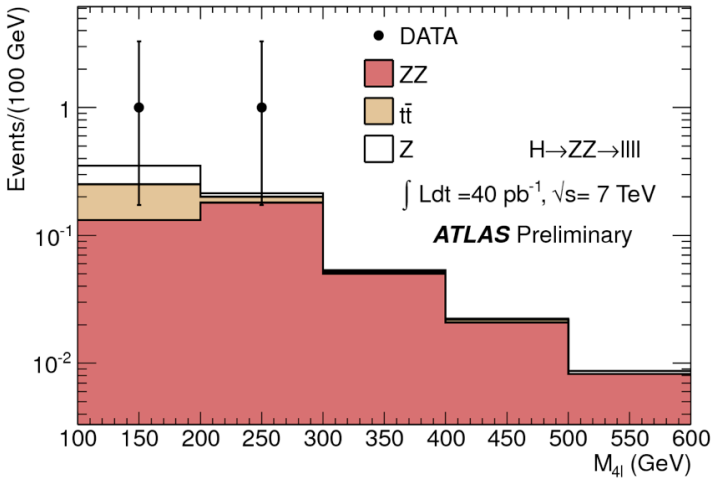
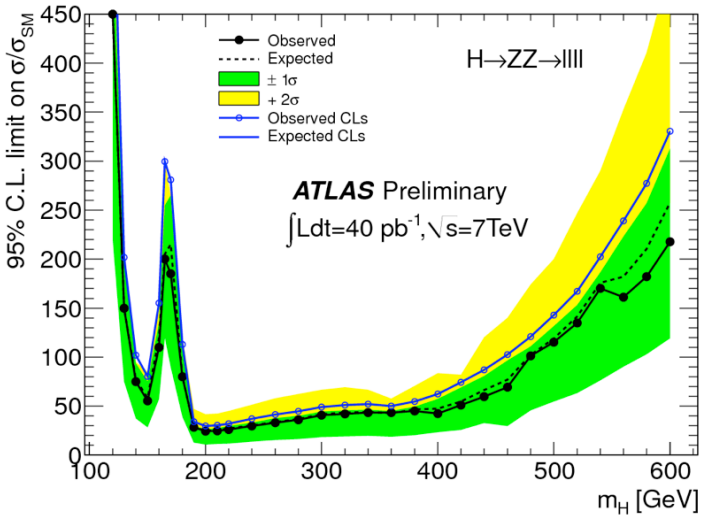
luminosity 40 pb^{-1}
exp limit@200 GeV/SM 25
obs limit@200 GeV/SM 24

Higgs → ZZ → 4ℓ

- Production: gluon fusion and vector boson fusion. Sensitivity 130 < M_H < 600 GeV
- Event selection: 2 same flavor lepton pairs with opposite charge
- Lepton selection: electrons E_T>20GeV, isolation<30%, muons p_T>7 GeV, iso<20%
- ZZ background irreducible. Others can be suppressed with tight constrain on the dilepton mass. Other backgrounds: Z+jets and top-quark pairs
- ZZ* predicted from Z yield, Z+jets and top pairs estimated with MC after detailed study
- Systematic uncertainties: lepton reconstruction and ID, sample normalization, cross sections of signal and background processes
- Neyman Construction based on profiled likelihood ratio for limit extraction





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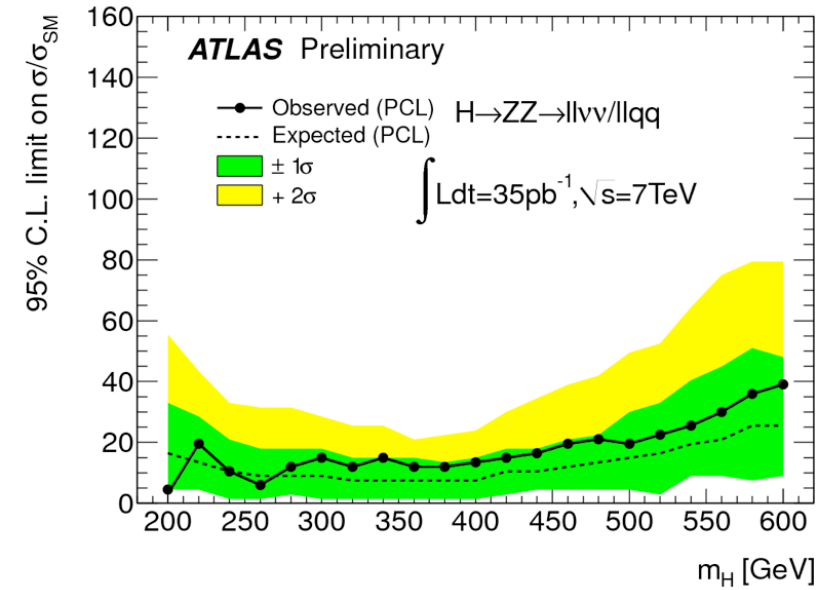
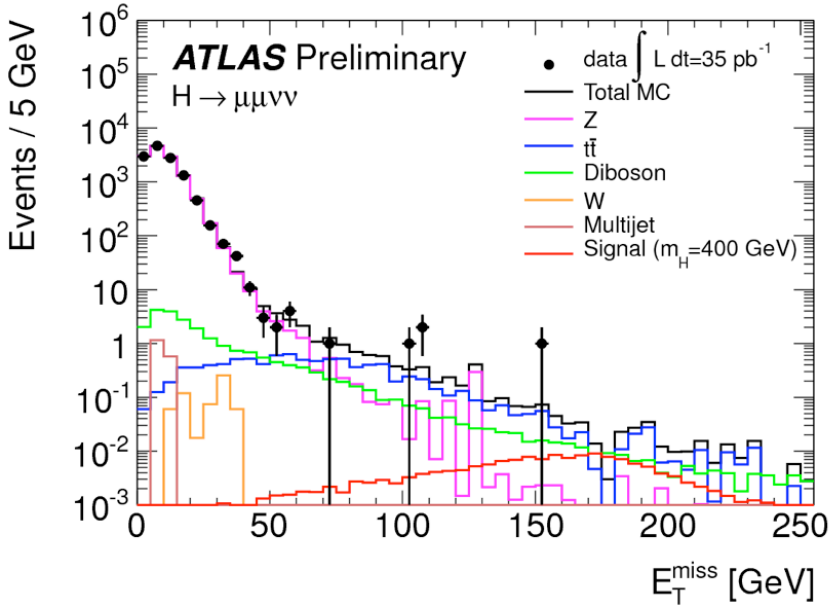
luminosity 35 pb^{-1}
exp limit@400 GeV/SM 7
obs limit@400 GeV/SM 14

Higgs → ZZ → 2ℓ+2υ/2 jets





- While not as clean as the 4 lepton channel, yield is larger. Only high mass: both Z on-shell
- Backgrounds: top paris, W+jets, dibosons, QCD
- Event selection
  - 2 good electrons or muons, with invariant mass consistent with a Z
  - at least 2 jets and low missing E_T
  - or larger missing E_T
- Systematic uncertainties:
  - Luminosity uncertainty 11%
  - theory signal cross section, about 15%
  - object reconstruction, ID and energy scale
- Limits from Neyman construct on profiled likelihood method with m_{lljj} or m_T templates

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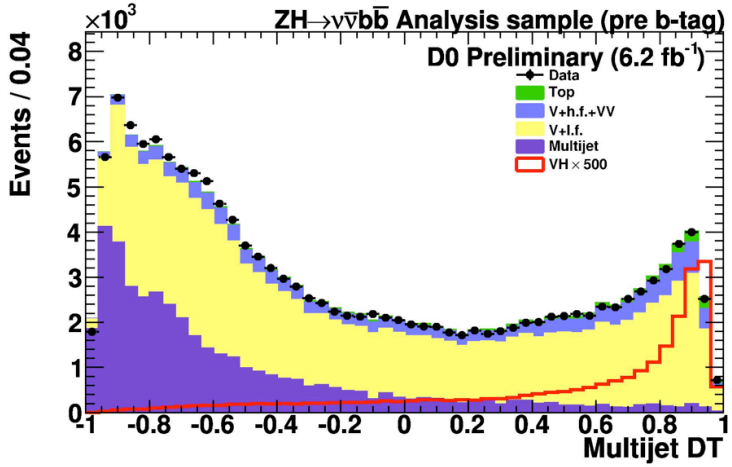
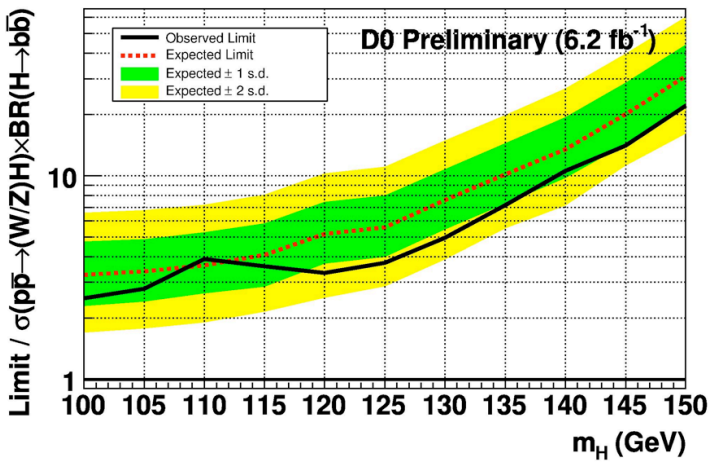
luminosity 6.2 fb^{-1}
exp limit@115 GeV/SM 4.0
obs limit@115GeV/SM 3.4

ZH → υυbb

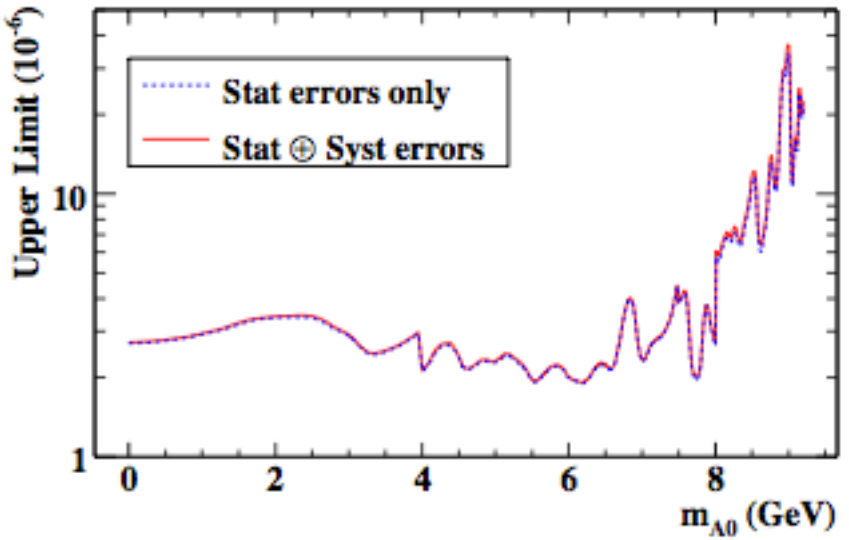
- Event selection: no more than 3 taggable jets with E_T>20GeV and missing E_T>40GeV (missing E_T signigicance > 5)
  - 1 or 2 jets identified as b-jets with a BDT trained for discriminating against light flavor jets
  - leading jets not-back-to-back, missing E_T aligned with missing p_T
- Multijet background estimated from data, while other SM processes with MC
- Limits: log-likelihood ratio, systematics as gaussian constraints:
  - multijet background modeling and b-tagging





Light Higgs from Υ(1S) decays

- Search for a decay of Υ(1S) to a single photon and an invisible Higgs
- Strategy: search for single-photon decays of the Υ (1S) resonance
  - events tagged with transition $\Upsilon(2S) \rightarrow \pi^+\pi^-\Upsilon(1S)$
  - select events with single energetic photon and large missing E
- Event selection:
  - two opposite charge tracks and one photon with E>0.15GeV
  - veto on additional energetic photons and energetic tracks and specific cuts to reduce neutrals background
- Signal/background discrimination enhanced by NN, several other cuts applied
- The largest systematic uncertainty is on the reconstruction/trigger/filter efficiency
- Likelihood scans preformed with
  - dipion recoil and missing mass
  - no discrepancy with background found in 14.4 fb^{-1}



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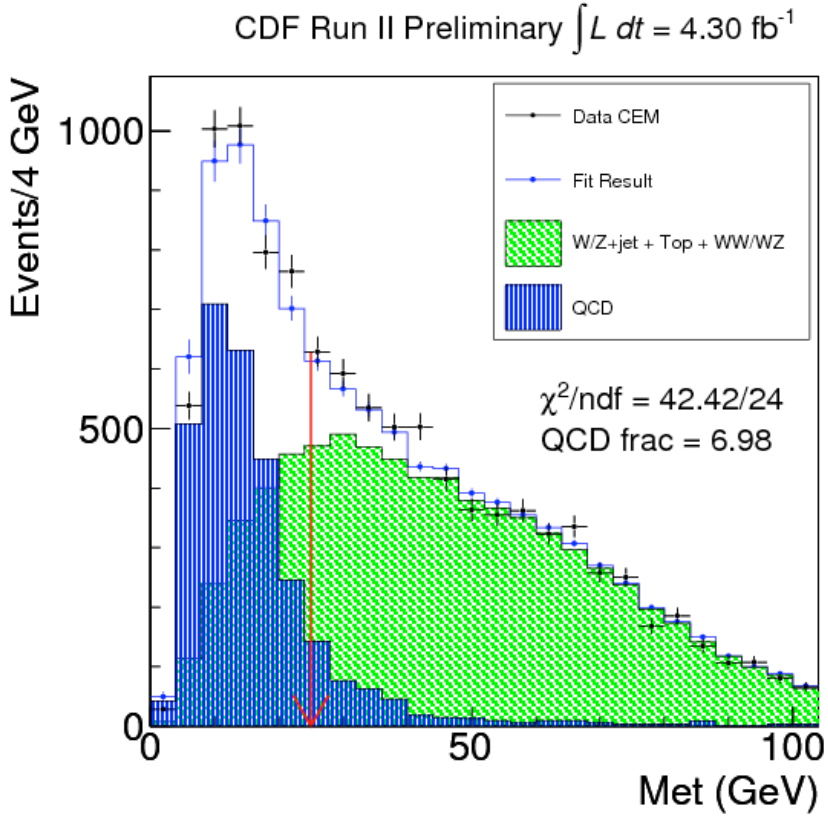
luminosity 4.3 fb^{-1}
excess significance 3.2
excess centered at 144 GeV

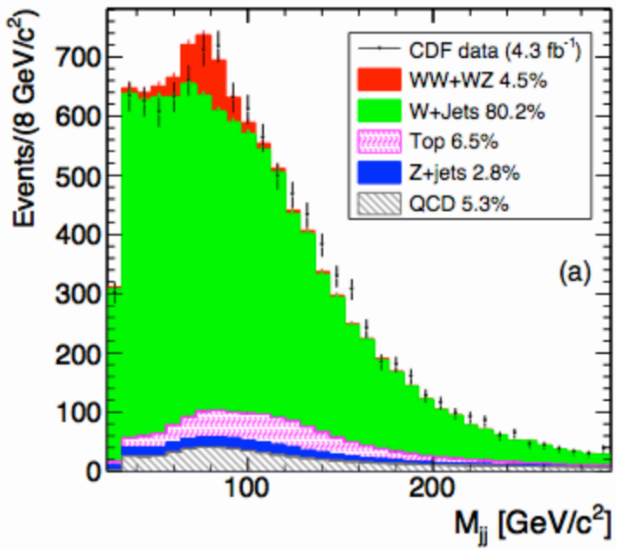
W + 2 jets final state

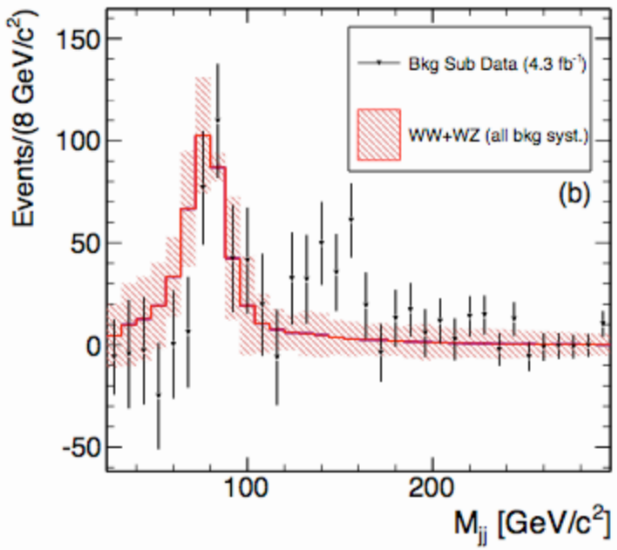
- Dijet mass resonances already used for measuring the cross section of diboson processes WW, WZ: same final state
- Study Dijet mass above 100 GeV
- Event selection
  - one central isolated electron/muon, E_T>20 GeV
  - missing E_T > 25 GeV
  - transverse mass m_T > 30 GeV
  - 2 jets, E_T> 30GeV, dijet p_T>40GeV
- Main backgrounds: W+jets, QCD, top, Z
  - estimated from MC, except for
  - QCD: isolation sidebands
- Background reduction:
  - lepton isolation: cancel semilep decays
  - Δφ(MET, leading jet) > 0.4
  - veto events with extra leptons

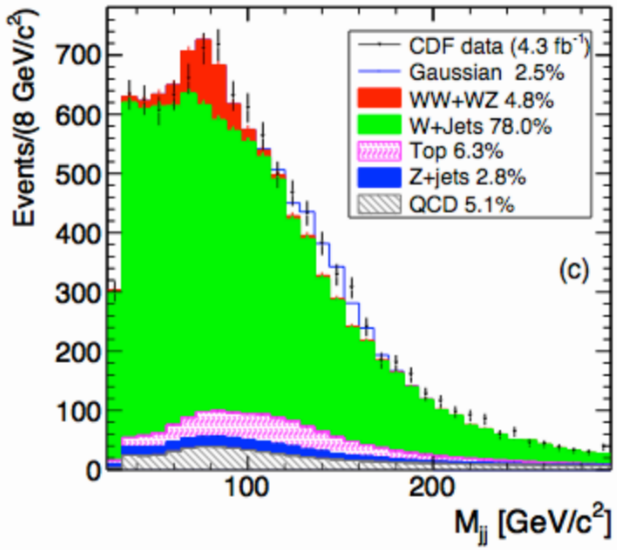


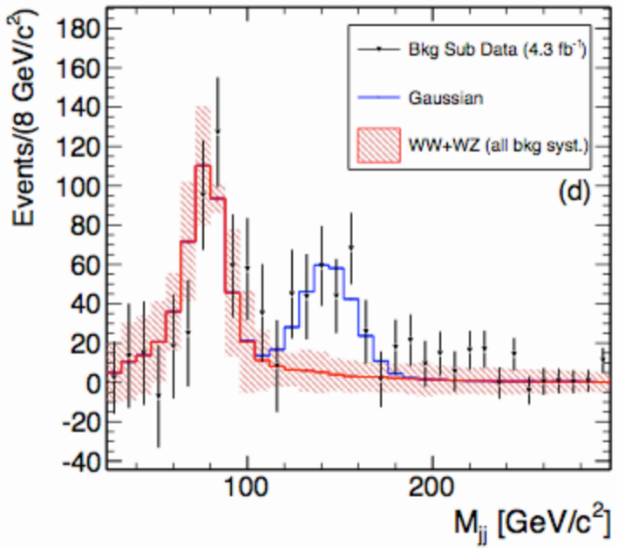
W + 2 jets final state

- χ^2 fit performed letting the W+jets normalization float, while constraining the other backgrounds to their measured cross sections
- Excess modeled with gaussian, width corresponding to a narrow resonance
- Significance: 3.2 standard deviations









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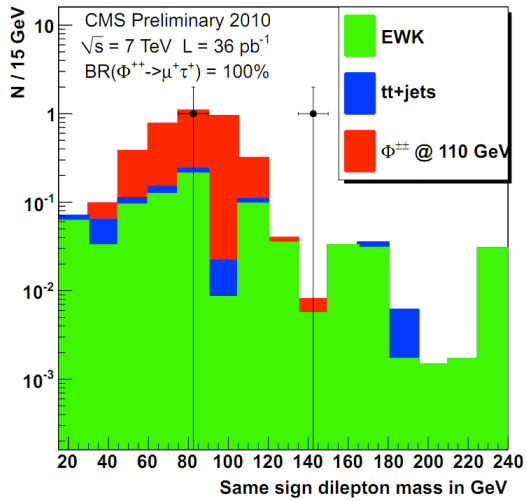
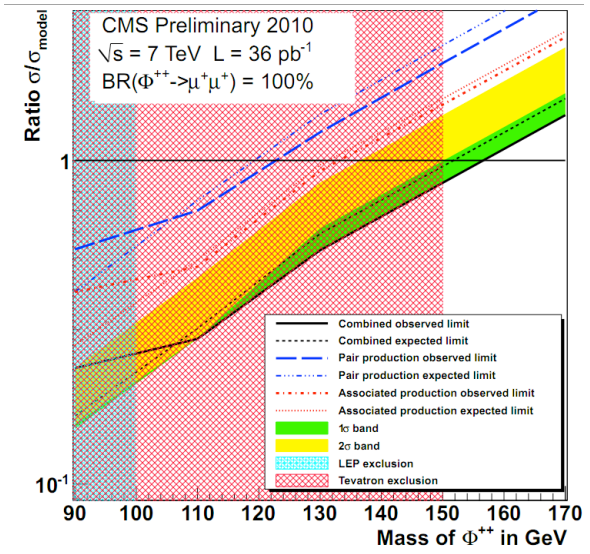
luminosity 36 pb^{-1}
obs limit in ee 144 GeV
obs limit in μμ 156 GeV

Doubly charged Higgs → ττ

- Inclusive search for production of $\varphi^{++}\varphi^{-}$ and $\varphi^{+}{}^{+}\varphi^{-}{}^{-}$
- Search focuses on mass range where WW decay is not allowed
- Masses of the double and single charged Higgs is assumed degenerated
- Three or four lepton final state, no more than one hadronic tau
- Event selection: 3 or 4 isolated leptons, with additional optimized clean up cuts
- There are no doubly charged resonances in SM:
  - backgrounds are due to misidentification or mismeasurements: charge, Z+jets
  - estimation done in MC and crosschecked in control regions
- Main uncertainties due to tau-ID and statistics of sidebands (background estimation)





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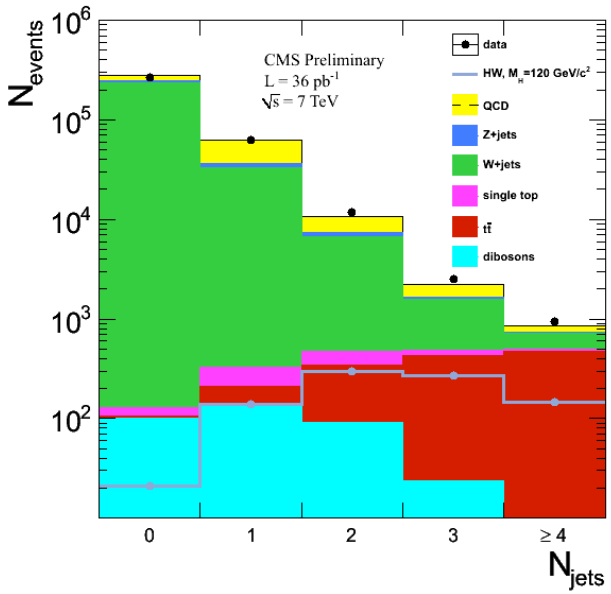
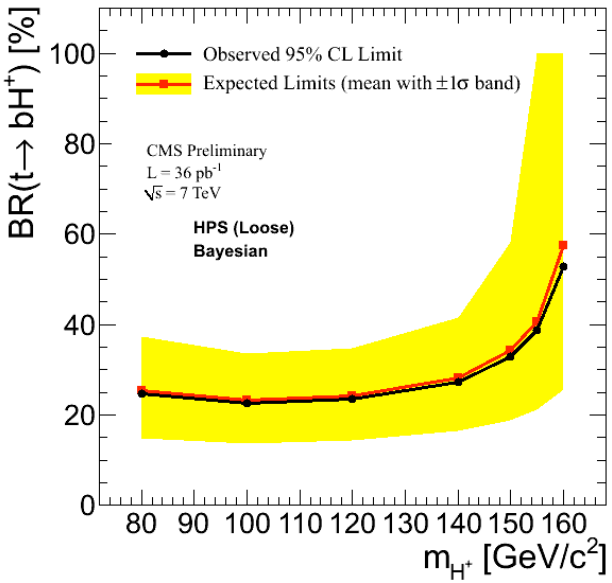
Charged Higgs → τν

luminosity 36 pb^{-1}
exp limit@150 GeV tanβ= 30
obs limit@150 GeV tanβ= 23



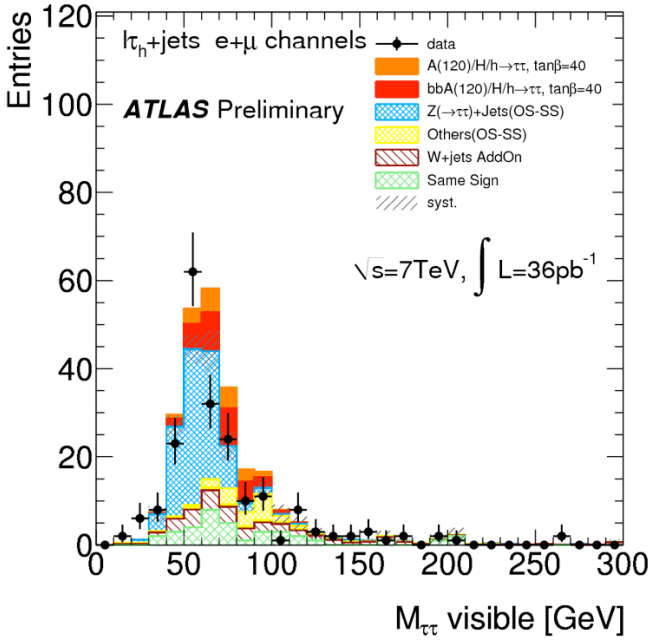


- Search in top-pair dilepton sample, eτ and μτ, where one of the top quarks decays to a charged Higgs
- Event selection requires additionally at least 2 jets, p_T > 30 GeV, and large missing E_T > 40 GeV
- "Fake tau" backgrounds are estimated from data (fake rates): top pairs in the lepton+jets channel and W+3jets
- Non-fake backgrounds are estimated from MC: Z +jets and top pairs in dilepton channel
- Bayesian method is used for extracting the limits on the BR of the top quark to a charged Higgs
- Systematic uncertainties are accounted in the fit, including the uncertainty on the "fake" background and the energy scale

Yale

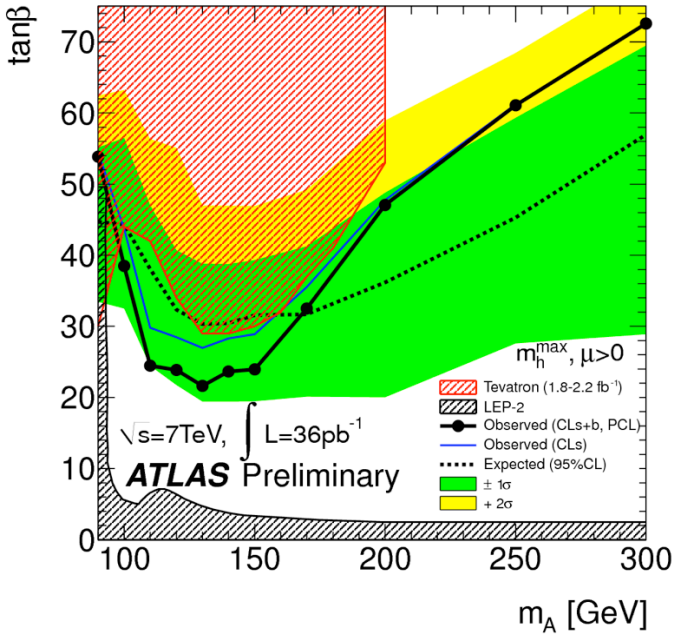
luminosity 36 pb^{-1}
exp limit@150 GeV tanβ= 31
obs limit@150 GeV tanβ= 21

Neutral MSSM Higgs → ττ



- Event selection:
  - one hadronic tau, E_T > 20 GeV
  - one opposite charge leptonic tau
    - E_T > 20 GeV electron
    - p_T > 10 GeV muon
  - small m_T(lepton,missing E_T)

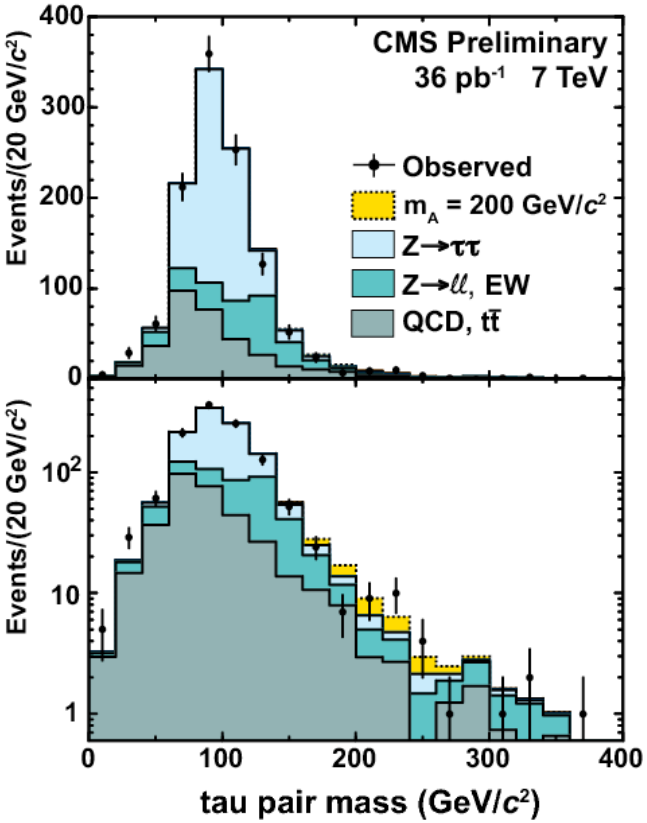
- Backgrounds:
  - W+jets and QCD: fake estimation from same-sign pairs
  - Z+jets: τ embedding Z→μμ
- Limit setting: profile likelihood on visible dilepton mass templates
- Systematic uncertainties are accounted as nuisance parameters in the fit



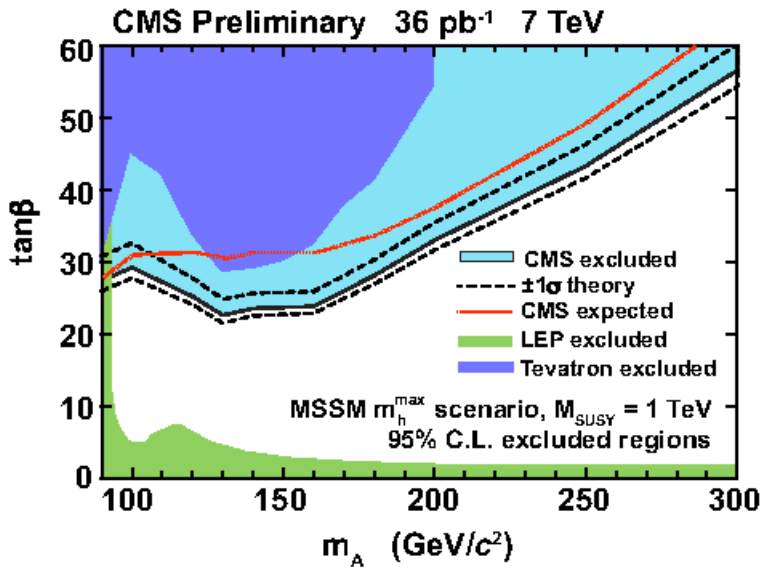
Yale

luminosity 36 pb^{-1}
exp limit@150 GeV tanβ= 30
obs limit@150 GeV tanβ= 22

Neutral MSSM Higgs → ττ



- Search for eτ, μτ and eμ final states
- Full event kinematics reconstructed with a likelihood method
  - takes into account all the info available and results a gaussian centered in the true Higgs mass
- Event selection requires two isolated oppositely charged leptons with low M_T
- Main backgrounds are Z, QCD and W+jets
  - Z: estimated from MC, normalized to μμ decay
  - jets: estimated with same-sign events



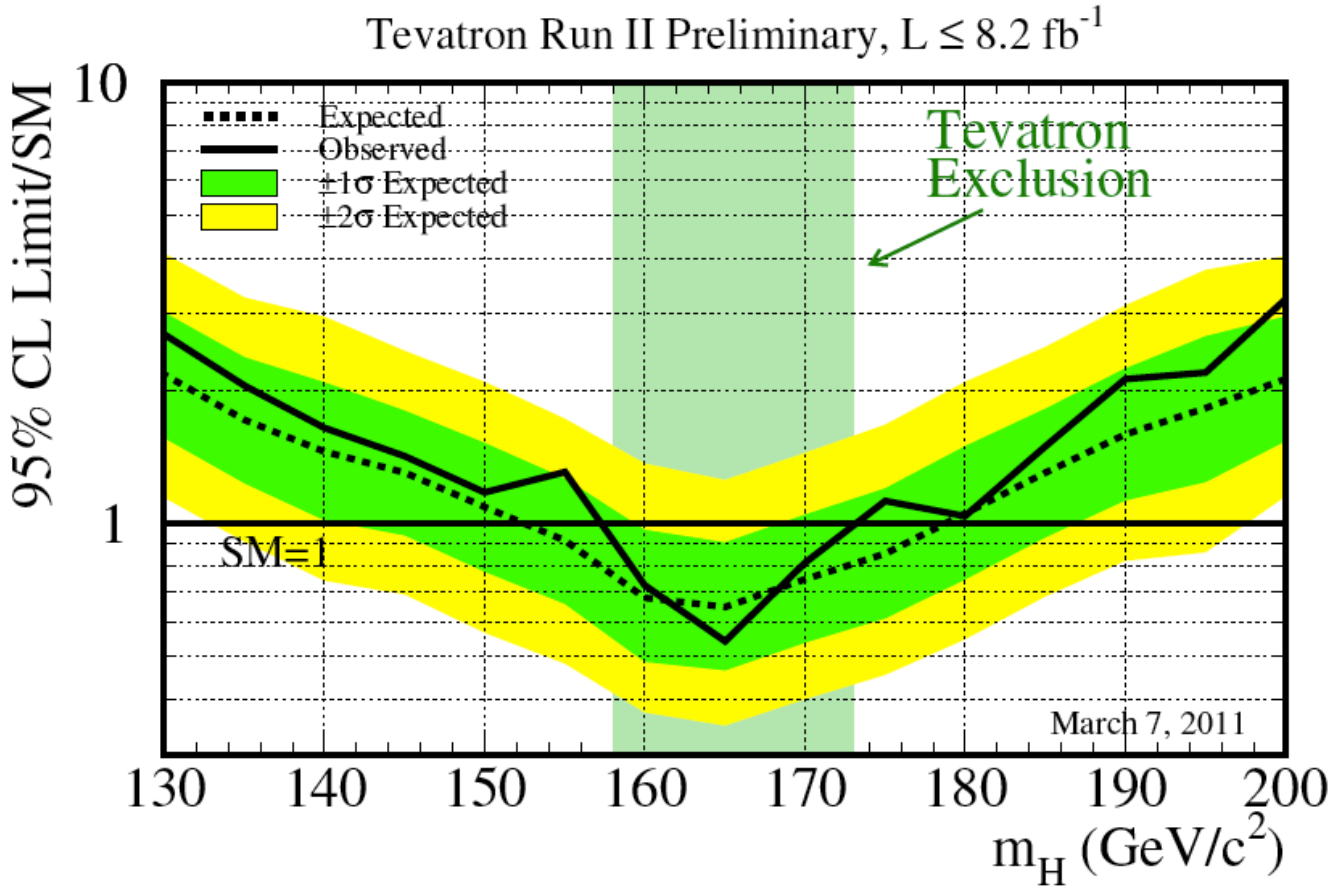
- Main systematic uncertainty is related to tau-ID, and the normalization of the QCD background
- Likelihood fit, marginalizing systematics as nuisance parameters

Yale

luminosity up to 8.2 fb^{-1}
excluded 158 < m_H /GeV < 174

High mass combination

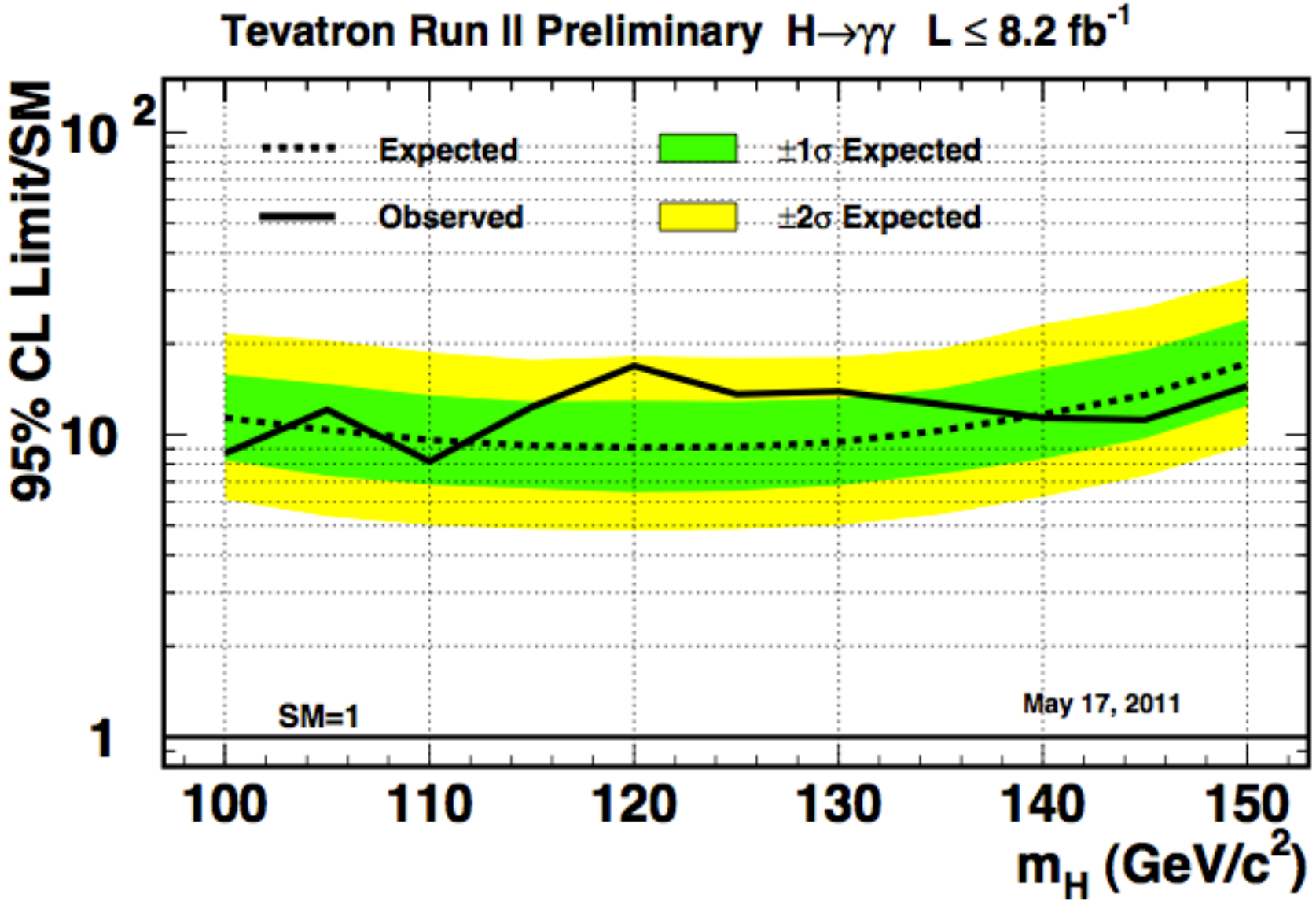
- Includes all WW final states available, and some γγ and ττ from D0
- SM cross sections:
  - gg→H, VBF and associate production have been calculated to NNLO
  - with MSTW NNLO PDFs



Yale

luminosity up to 8.2 fb^{-1}
exp limit@115 GeV/SM 9.0
obs limit@115GeV/SM 12.0

Higgs → γγ combination



Conclusions

- Big efforts being devoted in all experiments towards finding the Higgs
  - many new results in all different channels
- We didn't find it yet, but sensitivity keeps improving
  - Exclusion area is more and more robust
  - BSM searches are excluding more and more parameter space
- We expect several updates for the summer, including new combinations and very competitive results from the LHC